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Conference Title

Reducing the current harmonics of a wind farm generation based on VSC-HVDC transmission line by shunt active power filters

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Abstract

Clean energy refers to forms of energy that do not produce hazardous emissions, do not harm human and ecosystem health and do not destroy the environment during extraction from the Earth. One of these clean energies is wind power. Energy generated from the power of wind uses a passive form of energy collection; the system works by the force of wind and does not need any added energy. Integration of massive amount of wind power is a major challenge to power industry. One of the big issues is how to collect the wind power and feed it into the AC grid. The HVDC technology based on voltage source converter (VSC), has recently been an area of growing interest to solve this issue. Although VSC-HVDC provides solution for the connection of wind farms to the grid, some problems occur in this method. One of them is current harmonics. This paper focuses on using shunt active power filter in order to mitigate the harmonic currents produced by HVDC converters.

Keyword: Wind farm generation, shunt active power filter; high voltage DC (HVDC); voltage source converter (VSC)

1. Introduction

The wind energy sector experiences a huge growth all over the world. While in the early 90´s only single turbines with power rating of less than a hundred KW were installed, today offshore wind farm (OWF) are planned with capacity of more than 1000 MW.
Major factors that have accelerated the wind-power technology development are as follow [1]:

- High-strength composites for constructing large low-cost blades
- Falling prices of the power electronics
- Variable-speed operation of electrical generators to capture maximum energy
- Improved plant operation, pushing the availability up to 95 percent

Some areas have extremely good conditions for establishment of wind power generation farms. However transmission lines will not be able to handle and export the surplus energy from these areas to

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consumption areas [2]. To transmit power over such a long distance creates challenges for the wind farm developer and the network operator. Two alternative methods are available for the connection of offshore wind farm to the grid, namely high voltage AC (HVDC) and high voltage DC (HVDC) [3]. Although HVAC provides simplest and most economic connection method for short distances, HVDC transmission becomes the only feasible option for connection of a wind farm when the distance exceeds 100-150km [4]. HVDC traditionally has been used to transfer large amounts of power over long distances. But for traditional HVDC the reactive power cannot be controlled independently of the active power. The HVDC technology based on voltage source converters (VSC), has recently been an area of growing interest due to a number of factors, like its modularity, independence of ac network, independent control of active and reactive power, low power operation and power reversal etc. the voltage source technologies also facilitate the connection of several converters to a common dc-bus, forming an HVDC grid [5].

Besides the many advantages of VSC-HVDC links for wind farm generation, there are still some disadvantages associated with these transmission lines. In general, the VSC-HVDC presents itself as nonlinear impedance to its supplying wind farm generation system, generating harmonic currents with such adverse effects as lower power factor, more electromagnetic interferences, and more voltage distortions [6]. These disadvantages have prompted researchers and power electronic engineers to propose a solution for minimizing or alleviating such harmonics.

Conventionally, passive filters were implemented to reduce the current harmonics produced by nonlinear loads. However, these types of filters are not able to solve random variations in the load current wave form; greatly depending on power system parameters, they can also produce series and parallel resonances with the source impedance [7]. Active power filters have been developed to overcome the disadvantages of passive filters and to provide a more reliable and flexible compensation. This paper aims to utilize an active power filter to mitigate the harmonics associated with HVDC converters.

The scope of this manuscript is as follows: section 2 provides a clarification of basic wind farms and its corresponding control. Shunt active power filter system and its control method on a basis of p-q theory are explained in section 4. Finally, section 5 covers the time domain simulation results.

2. Wind turbine system

The wind turbine captures the wind's kinetic energy a rotor consisting of two or more blades mechanically coupled to an electrical generator. The turbine is mounted on a tall tower to enhance the energy capture. Numerous wind turbines are installed at one site to build a wind farm of the desired power production capacity. Obviously, sites with steady high wind produce more energy over the year.

The relation between the wind speed and mechanical power is given by equation 1 [8]:

$$p_w = \frac{1}{2}\,\rho\pi R^2 V_w^3 C_p(\theta,\lambda) \tag{1}$$

Where p_w is the power extracted from wind (W), ρ is the air density (kg/m^3), R is the radius of the rotor of wind turbine (m), V_w is the wind speed (m/s), θ is the pitch angle of the rotor (deg) , $\lambda = \frac{w_{rot}R}{V_w}$ is the tip speed ratio, in which w_{rot} is the rotor speed of wind turbine (rad/sec), C_p is the aerodynamic efficiency of the rotor which can be expressed as a function of the tip speed ratio (λ) and the pitch angle (θ) by the following equation [8]:

$$C_p = 0.22\left(\frac{116}{\beta} - 0.4\theta - 5\right)e^{\frac{-12.5}{\beta}} \tag{2}$$

And β can be expressed by:

$$\beta = \frac{1}{\frac{1}{\lambda+0.08\theta} - \frac{0.035}{\theta^3+1}} \tag{3}$$

The resultant mechanical power is transferred into electrical energy by a generator before being fed into the grid.

3. Active Filter for sinusoidal current control

The VSC-HVDC presents itself as nonlinear impedance to its supplying wind farm generation system, producing harmonic currents with several adverse effects [6]. In order to reduce these unfavourable current harmonics, the present paper focuses on active power filtering. The function of shunt active filters is to compensate the harmonic current for a selected nonlinear load. Their controller determines the compensating current reference and forces a power converter in real time, to accurately track the changes in its harmonic current [9]. The harmonic and reactive power compensation is a method which makes the active filter to compensate the current of a nonlinear load. This makes active filter to force the compensated source current to become sinusoidal and balanced. A systematic mathematical formulation of p-q theory is given in [9].

The instantaneous real power (p) and reactive power (q) of the load can be further divided into DC and AC components as given below:

$$p = \tilde{p} + \bar{p}\,,\;\; q = \tilde{q} + \bar{q} \tag{4}$$

Where, $\bar{p}, \bar{q}$ are the DC components of real and reactive power; $\tilde{p}$ and $\tilde{q}$ are the AC components of real and reactive power, respectively.

It should be noted that the system voltages may be distorted by the harmonic currents as well as the ripple generated by the active filter. Therefore, the current calculated by the previous equation will not exactly compensate the harmonic. So, a Fundamental Positive Sequence Voltage Detector (FPSVD) is used for determining the amplitude of positive sequence of voltage and the output of this block is pure sinusoidal phase voltages (V_a', V_b', V_c') which are used to synchronize the filter currents and also to calculate the instantaneous powers.

If the shunt active filter compensates the power $\tilde{p}$ and q of the calculated powers (p, q), it is compensating all components in the load current (including the fundamental negative-sequence component). A block diagram of the active filter for sinusoidal current control is shown in Fig.1.

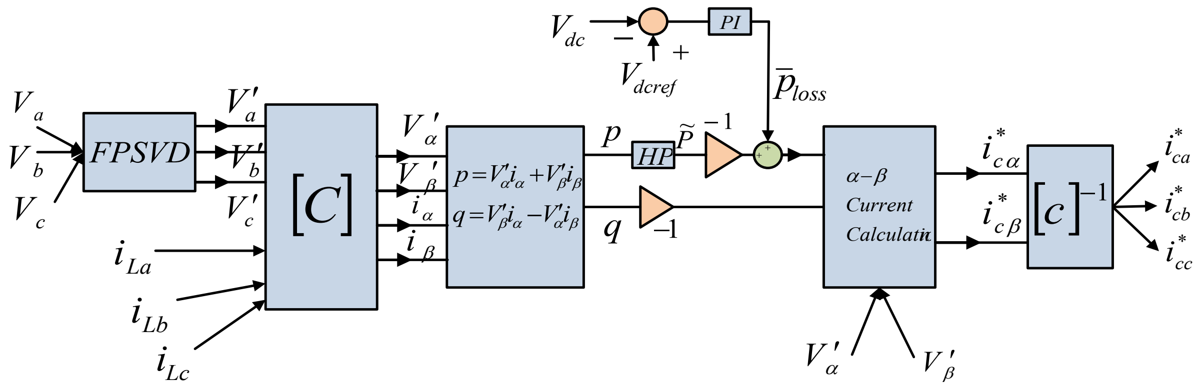


Fig. 1. Power control blocks of the SAF

4. Simulation Results

In order to verify the performance of proposed shunt active power in mitigating the harmonics associated with HVDC-based wind farm generation of the power system, an appropriate simulation for the system was performed. Time-domain simulations were carried out with PSCAD/EMTDC software. The parameters of the system are listed in Tables 1 and 2.

Table 1. wind turbines and HVDC parameters

Fixed Speed Induction Generators	
Base voltage	4kV
Base power	2MVA
Frequency	50 Hz
Base speed	314 rad/s
Stator resistance	0.066 p.u
Magnetizing resistance	3.86 p.u
Magnetizing inductance	0.105 pu
Leakage inductance	0.046 pu
Wind turbines	

Rotor radius	60 m
Rotor area	11304 m^2
Air density	229 kg/m^3
Gearbox efficiency	0.97 p.u
Wind speed	10 m/s
HVDC system	
DC cable	100 km
R_{dc}	5Ω
Number of conductors	2
C1,C2 (capacitors of sending end VSC)	250 μF
C3,C4 (capacitors of receiving end VSC)	220 μF
Switching frequency	3 kHz
Fundamental frequency	50 Hz

Table 2. Active power filter parameters

Ripple filter	
L	1 mH
C	0.1 μF
R	0.02 Ω
Active power filter	
Base power	100 MVA
Base voltage	13.8 kV
Nominal frequency	50 Hz
Transformer Base power	100 MVA
Transformer windings	YD
Transformer ratio	13.8/6.75 Kv
Switching frequency	2 kHz
DC link capacitance	2000 μF
Reference value of DC link voltage	3 kV
Hysteresis band	0.001

In this section, shunt active power filter operates at time 5seconds and its duty is to alleviate the harmonic currents of VSC-HVDC transmission system. Fig.2 shows the generated active power with fixed-speed wind farms. The power generated by wind farm is purely constant before operation of active filter at time 5seconds. When active filter performs, the generated power is faced with small oscillations which are completely damped after a few seconds. It should be noted that the wind turbine begins to operate at time 2seconds after the system operates with constant voltage sources.

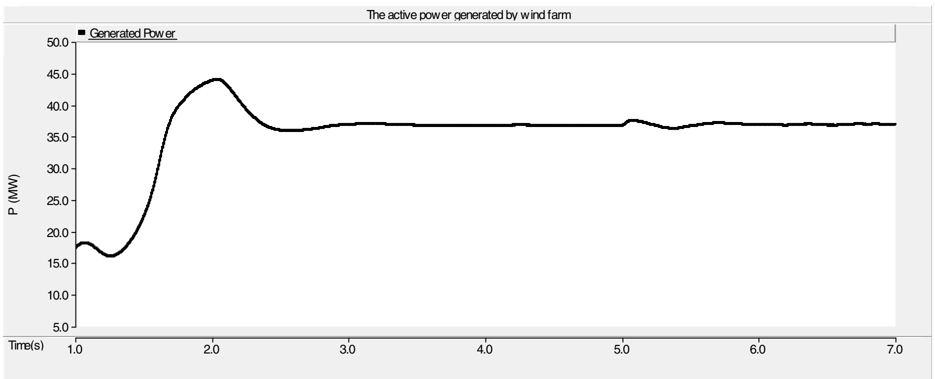
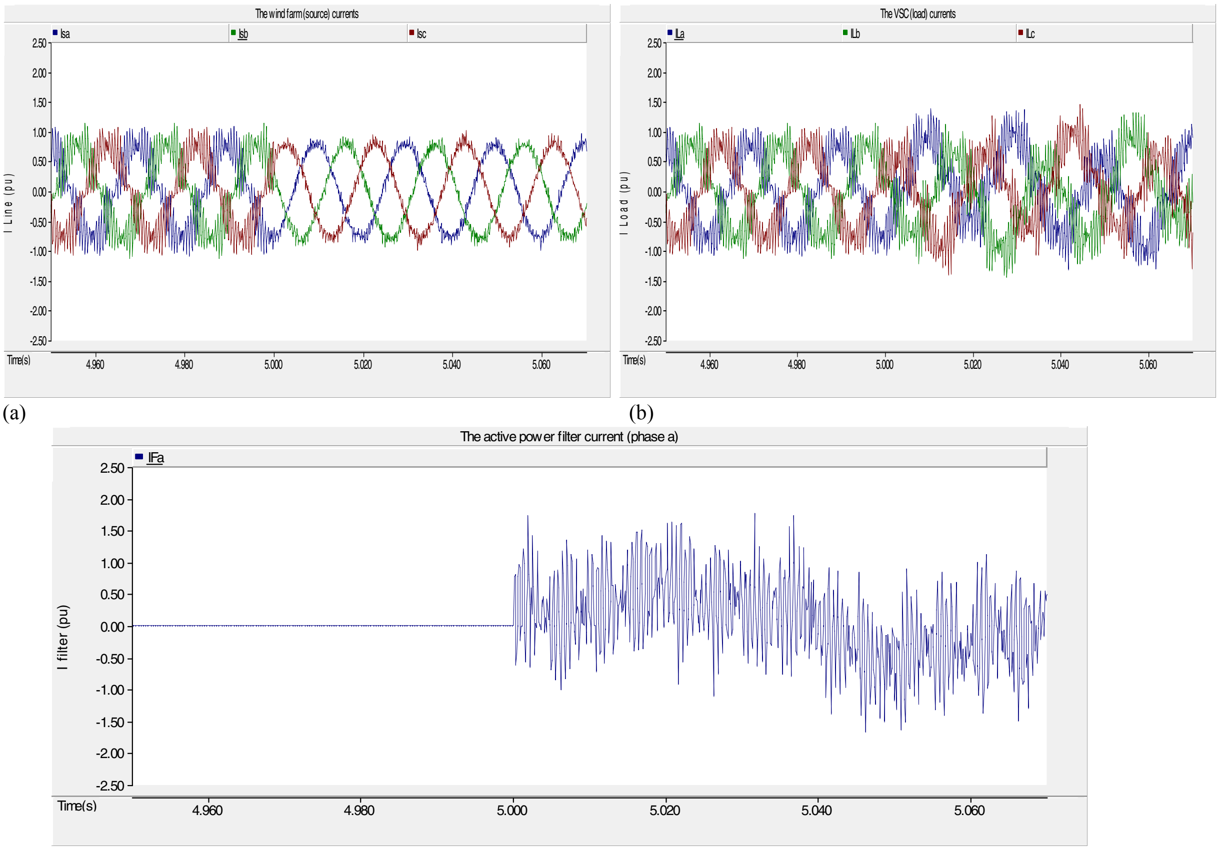


Fig. 2. The active power generated by wind farm

Fig.3 (a, b, and c) demonstrates the wind farm side-current, the VSC-HVDC current, and the current produced by shunt active power, respectively. From Fig.3-b, it can be obtained that the load current (VSC-HVDC) contains a notable harmonic form which distorts the source current (i.e. wind farm side-current) though, after operation of shunt active power filter, harmonic current of the load can be well attenuated and the compensating current can track the harmonic one effectively. As it can be seen in Fig.3-a, the utility currents are nearly sinusoidal after operating the active power filter. This verifies that the proposed three-phase active power filter can suppress the harmonic currents. Fig.3-c exhibits the current generated by active power filter in order to compensate the harmonic currents of the load. The shunt active power filter proposed here can perform the harmonic attenuation without any passive filters; however, if a passive filter were designed for this power system, the power rating of active power filter would be greatly declined.

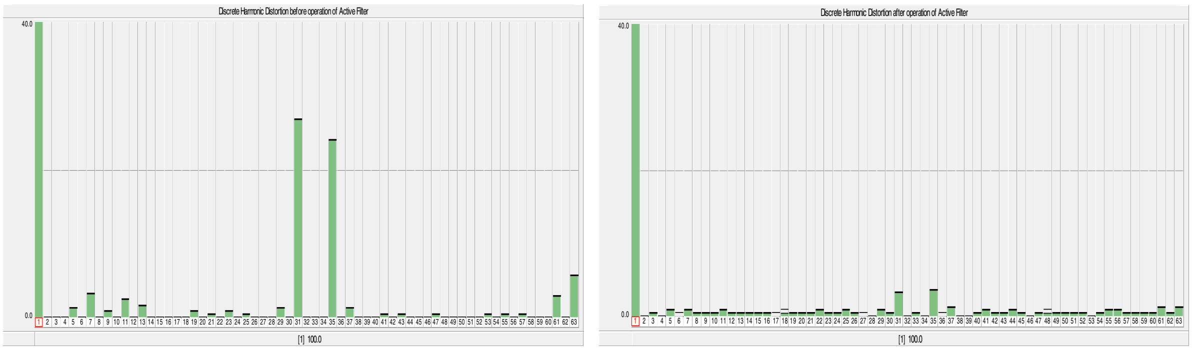


(a) (b)

(c)

Fig. 3. Simulation results for current at the different sides of the power system: (a): the wind farm (source) currents. (b): the VSC (load) currents. (c): the active power filters currents

Fig.4-a shows the spectrum of wind farm side (source)-current depicted earlier in Fig.3-a before operating the active power filter. It can be observed in Fig.4-a that the source current contains a great value of high harmonic orders (31, 35, 61, and 63) besides such low order harmonics as 5, 7, 11, and 13. Furthermore, it should be noted that the amplitude of the high order harmonics is much greater than the low order ones; as formerly shown in Fig.3-c, the active filter is more likely to compensate the high order harmonic than the low order ones; that may be the reason behind the fact that the active filter current contained high frequency orders.



(a) (b)

Fig. 4. Discrete harmonic distortion of each harmonic order (a) before (b) after operation of active filter

Fig.4-b shows the first 63 order harmonics of wind farm side-current after operation of shunt active power filter. Total harmonic distortion of wind farm side-current both after and before operating the active power filter is included in Table 3. It is considerable that the THD is decreased from 37% to 6% after active power filter operation. Furthermore, there is no passive filter supplemented to an active one and the harmonic attenuation is achieved only by active power filter. It can be observed in Fig.4-b that the active filter not only compensates the high order harmonics in a great value, but it also decreases the lower harmonic orders in such a significant way that the three-phase utility currents become nearly sinusoidal.

Table 3. THD of generation side current in two cases

Case	Without Active power filter	With Active power filter
THD %	37.3%	6.2%

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